

## IX. Modes of operation

The Antiproton source can be oriented into several modes of operation based on the needs of users. In addition to antiproton stacking and unstacking, several operating modes were created that utilize protons. Protons provide a convenient source of relatively high intensity beam for tune-up and studies. The antiproton source has even been used to provide beam for experiments housed in the A50 pit. Each mode of operation that has been used to date is summarized below with the exception of transfers from Booster using the decommissioned AP-4 line.

### A. Antiproton stacking

A single Booster batch is accelerated in the Main Injector to 120 GeV. After the protons are bunch rotated, the short bunch length beam is extracted from the Main Injector. Beam is transported down the P1 and P2 lines, then is directed at F-17 into the AP-1 line (see figure 9.1). The protons move down the AP-1 line into the target vault where the beam strikes a nickel target. Downstream of the target, 8 GeV antiprotons, as well as other negative secondaries, are focused with the collection lens and are momentum selected with the pulsed magnet. Particles that are off-momentum or positively charged are absorbed in a beam dump. The secondary beam travels to the Debuncher via the AP2 line where most of the non-pbar secondaries decay away. Of the remaining secondaries, most are lost in the first dozen turns in the Debuncher. Only the small fraction of antiprotons with appropriate energy survives to circulate in the Debuncher. For every million protons on target,

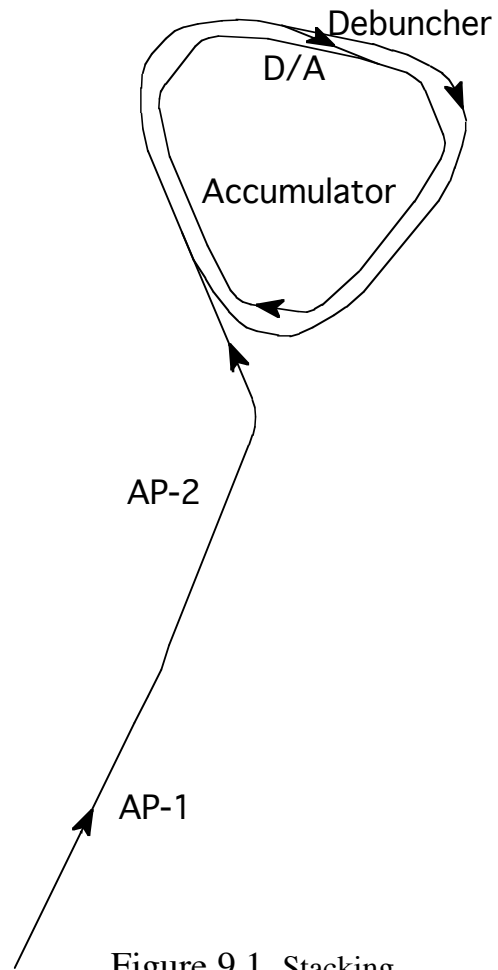


Figure 9.1 Stacking

only a dozen or two antiprotons make it to the core. After debunching and cooling in the Debuncher, the pbars pass through the D to A line and into the Accumulator. Successive pulses of antiprotons arriving into the Accumulator are 'stacked' over several hours or days into the core by ARF-1 and stochastic cooling. Significant TCLK resets are Booster \$14, Main Injector \$29, Debuncher \$81 and Accumulator \$90. Stacking cycles are at least 1.5 seconds in duration and may be extended to improve the stacking rate with larger stacks.

### **B. Antiproton transfer**

Pbars are unstacked from the Accumulator core with ARF-4 and accelerated to the extraction orbit. The ARF-4 voltage is increased to narrow the bunch, then ARF-1 is turned on to impart a 53 MHz structure on the beam. The Accumulator extraction kicker imparts a horizontal oscillation on the beam so that it passes through the field region of the extraction lambertson. The beam is bent upward by the lambertson and a C-magnet into the AP3 line (see figure 9.2). The beam continues down the AP-3 line, skirting the target vault, and enters the AP-1 line (running at lower currents for 8 GeV operation). The AP-1 line connects to the P2 line at F17 where 2 Lambertsons and 2 C-magnets bend the beam upward to the trajectory of the old Main Ring. Beam continues down the P2 and P1 lines, and is injected into the Main Injector. Significant TCLK resets are: Main Injector \$2A and Accumulator \$90 and \$9A.

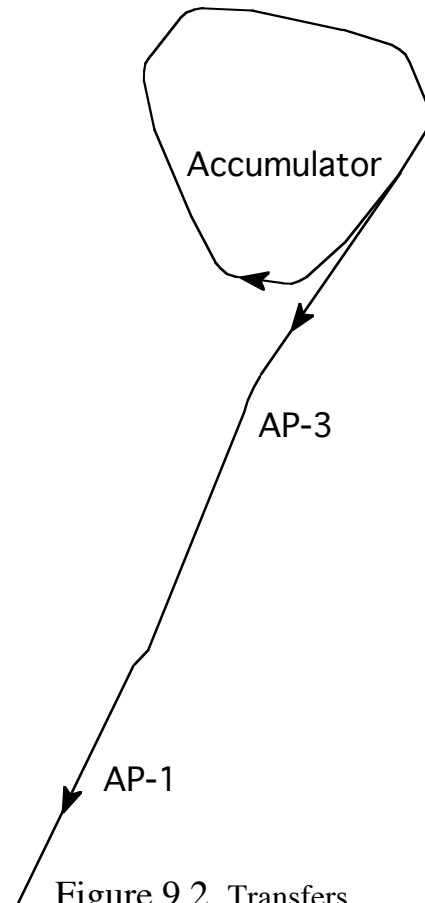


Figure 9.2 Transfers to Main Injector

### **C. Reverse protons**

Protons from the Booster are transferred to the Main Injector where their energy remains at 8-GeV until transferred. The protons trace the reverse path of the beam in an antiproton transfer. Beam is extracted into the P1 line, then continues down the P2 line until entering the field region of the F-17

lambertsons. The two lambertsons as well as two C-magnets bend the beam upward into the AP-1 line. The beamline is configured for 8 GeV operation by running the magnets from a separate set of power supplies. EB6 (powered by D:H926) bends beam into the AP-3 line, EB5 and EB6 make up a dogleg that diverts beam along the outside of the vault. After passing through AP-3 the beam continues through a C-magnet and the field region of the extraction lambertson which bends the beam upward into the Accumulator at A30. The extraction kicker in A20 deflects the beam horizontally onto the closed orbit of the Accumulator.

Reverse proton mode compliments

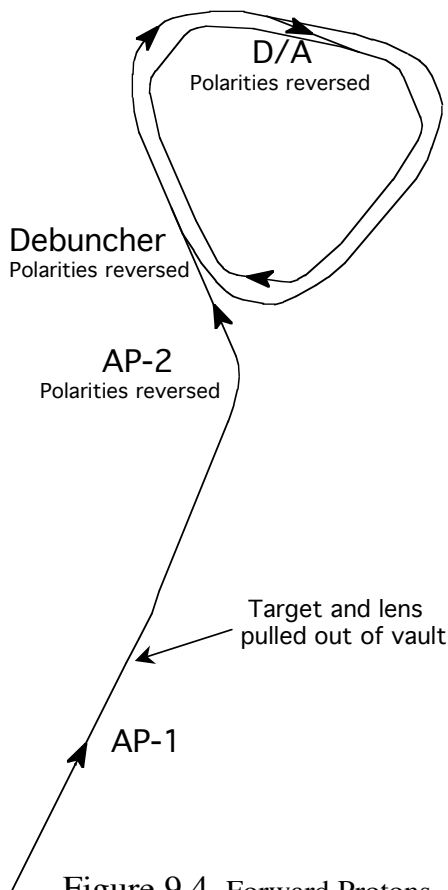


Figure 9.4 Forward Protons

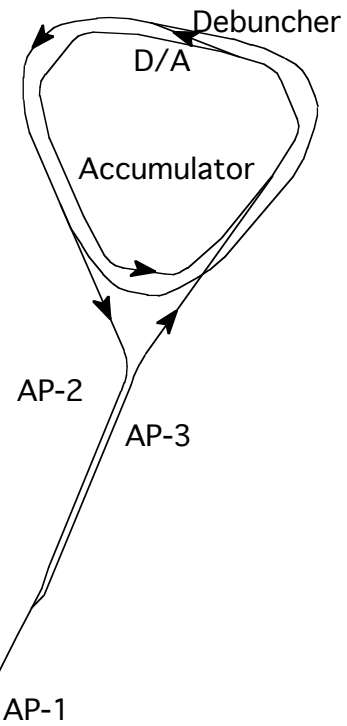


Figure 9.3 Reverse Protons

stacking in that the polarity of the Rings and beamlines do not need to be reversed. Reverse protons are used in Collider mode to tune up the AP-1 and AP-3 lines prior to an Antiproton transfer from the Accumulator to the Main Injector. Reverse proton mode is also used for high intensity studies in both rings and all beamlines. If desired, particles can be extracted from the Accumulator and sent down the D to A line into the Debuncher. Beam can then be injected backwards into the AP-2 line and transported to the target vault. Significant TCLK resets are a Booster \$16, Main Ring \$2D, and an Accumulator \$93.

## D. Forward protons

8 GeV protons are extracted from the Main Injector and continue into the AP-1 line in the same manner as in reverse proton mode. The similarities end there as beam is directed to the target vault instead of into the AP-3 line (see figure 9.4). In the target vault the production target and collection lens have been pulled out of the beamline and the polarity of the pulsed magnet has been reversed. The rings, and beamlines downstream of AP-1, have had their polarities reversed. This way the 8 GeV protons can continue into the AP-2 line, the Debuncher, the D to A line and the Accumulator as required. The proton beam could also be injected into the AP-3 line but it is normally more convenient to use reverse protons.

Forward proton mode can be useful for phasing cooling systems using higher intensity beams and other direction-specific studies in the source. This mode is most commonly used at the beginning of a running period to phase in the Debuncher cooling. Significant TCLK resets are a Booster \$16, Main Ring \$2D, and a Debuncher \$85.

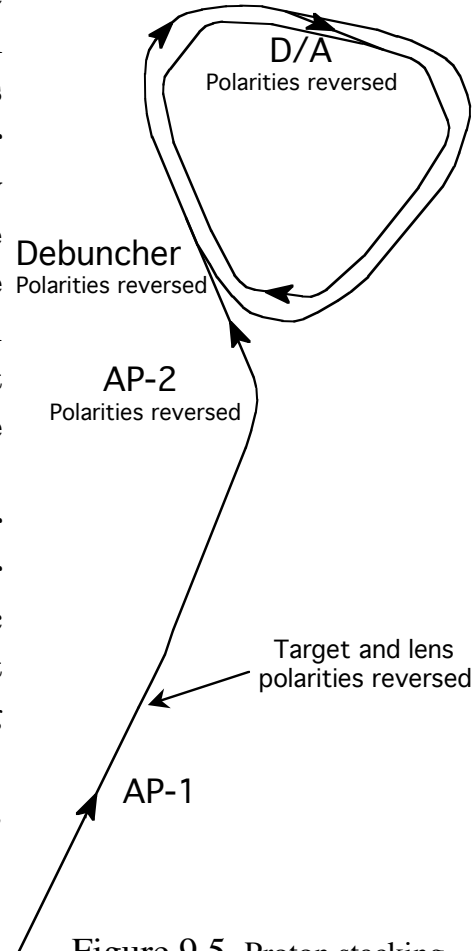


Figure 9.5 Proton stacking

### E. Proton stacking

In proton stacking mode the beam follows the same path as in antiproton stacking, but proton secondaries instead of antiproton secondaries are stacked (see figure 9.5). To accomplish this, polarities of components downstream of the target are reversed. In the target vault, 8 GeV protons are focussed, then charge and momentum selected because the polarities of the collection lens and pulsed magnet are reversed. The polarity reversal not only includes the rings, AP-2 and the D to A line but also the dampers and stochastic cooling systems.

Proton stacking has been used to test the limits of the stacking rate by stacking secondary protons instead of antiprotons. Proton secondary flux to

the Debuncher is about six times greater than that achieved with antiprotons. This is particularly useful for testing cooling systems under conditions simulating increased intensity. Proton stacking studies at the end of Collider Run 1b attained a peak stacking rate of 12.2 E10/hr (as opposed to 7.3E10/hr for antiproton stacking earlier in the run). Significant TCLK resets are the same as during stacking, a Booster \$14, Main Ring \$29, and an Accumulator \$81.

## **F. Deceleration**

In 1986, an experimental pit adjacent to Accumulator straight section 50 and a counting room attached to AP50 were constructed. The pit and counting room were built to provide space for experiments interested in using circulating Accumulator beam. Experiment E760 was the first to make use of the new facilities. The goal of the experiment was to measure the mass and width of charmonium states by means of  $\bar{p}$  - p collisions. A charmonium state is produced when a charm and anti-charm quark pair are produced and bound together, briefly orbiting each other. The quark pair is very short-lived, decaying in only  $10^{-20}$  seconds. The angular momentum from the spinning quarks contributes to their total energy. There are a number of different charmonium states defined by the rate at which the quarks rotate around each other.

The main components of E760 were a hydrogen gas jet target, which was the source of the protons, a particle detector, and the Accumulator, which provided the antiprotons. The gas jet target provided an interaction region of roughly one cubic centimeter. Circulating antiprotons in the Accumulator pass through the gas jet and some fraction of them interact with the hydrogen.

The Accumulator was modified to serve as a decelerator to reach the necessary energies, the lowest of which is at 3.770 GeV. Some of the desired resonances are located below the transition energy of the Accumulator. To reach these energies beam must be decelerated below transition. To accomplish a deceleration, all power supplies and an appropriate RF system were ramped down in a very precise fashion. Because the velocity of the beam was reduced during deceleration, the cooling system delays were also shortened to maintain the proper phasing. Quadrupoles, sextupoles and octupoles were also ramped to keep the tunes safely away from resonances.

Special code in the pbar front end provided the ramp waveforms necessary for the deceleration.

The beam is kept on the central orbit so that it is centered in the aperture in high dispersion regions. A new set of 2-4 GHz core momentum pickups were added that were sensitive to beam on the central orbit. The pickups used during collider operation are located at the core and were not suitable for beam on the central orbit. The 4-8 GHz core momentum pickups were mounted on a motorized stand and could be moved to the central orbit.

The E760 run took place during the 1990 Fixed Target run with the Antiproton Source dedicated to running the experiment. A typical sequence of events was as follows: a period of stacking to accumulate several  $10^{10}$  of pbars with the stacking cycles occurring in the 56 seconds between Tevatron injections. After the appropriate number of antiprotons was stacked, physicists and operators decelerated the beam from the MCR in a fashion similar to a shot set-up in Collider operation. After the deceleration was completed the experiment would conduct hours or days of data taking after which the cycle would repeat.

Experiment E835 was a progression of E760 and took data during the 1996-97 Fixed Target run. Among the improvements for E835 was an upgraded detector with a liquid Helium cooled calorimeter, which required a stand-alone Helium refrigerator at the AP-50 service building. This prompted the relocation of the A:QT power supply from AP-50 to AP-10 to provide room. Control of the deceleration ramps was integrated into the Pbar front end instead of an auxiliary front end as was done with E760. E835 was primarily interested in improving their statistics on the  $1P1$  resonance and also attempt to observe the  $\eta c'$  resonance which had never been observed.

E862 ran in parallel with E835. The experiment was involved with measuring anti-Hydrogen atoms created by the E835 gas jet. A separate beamline extended into the tunnel aisle downstream of A5B3. The beamline included a table that contained a stripping foil, magnets and a positron detector. Downstream of the table was a pair of dipole magnets and three wire proportional chambers, with the line ending with an antiproton detector.

When the Hydrogen jet interacts with the antiproton beam in A50 there are occasions when anti-Hydrogen is produced.

The anti-Hydrogen, which is neutral, is not bent by the A5B3 dipole and passes into the experimental beamline. At the table a stripping foil separates the positron from the antiproton. The particles pass through a small dipole, which bends the less massive positrons into a separate beamline that terminates in a positron detector. The antiproton continues down the beamline and passes through the two dipoles, eventually entering the antiproton detector. Experimenters hoped to measure the production rate and spectroscopy of anti-Hydrogen.

Not all experiments require a dedicated running period during Fixed Target operation. During collider run 1b experiment E868, also known as APEX (AntiProton EXperiment), had a successful run. Their goal was to make

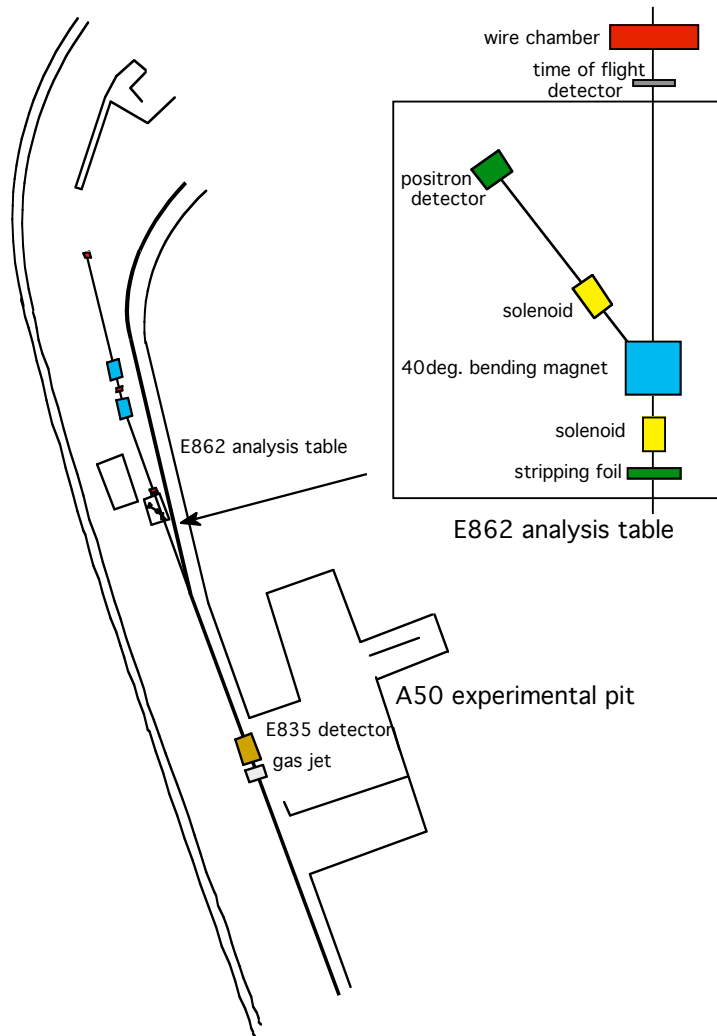


Figure 9.6 E835 and E862

a lower estimate of the lifetime of an antiproton. Most of their data-taking time was during stacking downtime or during shot set-ups.